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A Brief History of Boll Weevil Research and Eradication Efforts Since World War II

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Early emphasis in boll weevil management was placed on mechanical and cultural control. Even in 1910 the basic biology of the boll weevil was well understood, and its more important natural enemies were known. But interest in biological studies and biological control diminished in the 1930's when calcium arsenate was first used as an effective control of the boll weevil. Later, in the mid-1940's, the highly persistent arsenate was replaced by organic insecticides with the introduction of DDT, BHC, and Toxaphene. These were followed by other synthetic organic chlorinated hydrocarbon insecticides including aldrin, dieldrin, endrin, heptachlor, Strobane, and TDE. The new insecticides possessed two qualities of great importance: 1) high initial toxicity to the cotton pest insects, and 2) sufficient persistence to control newly emerging insects or insects migrating from untreated to treated areas.

The chlorinated hydrocarbon insecticides had a great impact on cotton production. For the first time, cotton producers were able to achieve highly effective control of all arthropod pests of the crop. It then became profitable for producers to increase the use of fertilizer and irrigation, and to incorporate long-growing indeterminate varieties. Spectacular yield increases were obtained at higher profit levels for the next 20 years.

The apparent victory over pest insects of cotton was not lasting. By the mid-1950's, the boll weevil in Louisiana and Mississippi had developed resistance to these chemicals. The resistant pest strain spread rapidly across the southern and southwestern states and all infested areas were reporting chlorinated-hydrocarbon-resistant weevils by 1960 (Roussel and Clower 1957; Brazzel et al. 1961).

This problem was solved by a switch to the organophosphorus (OP) insecticides, mainly methyl parathion, azinphosmethyl, ethyl parathion, and malathion. The organophosphorus compounds were highly toxic to the boll weevil at relatively low concentration rates, but higher rates were needed for the bollworm and tobacco budworm.

In 1958, the National Cotton Council passed a resolution that called for increased research and development to provide the technology for the eradication of the boll weevil from the United States. At the request of the House and Senate Agricultural Committees of the U.S. Congress, a working group was appointed by USDA to review the existing boll weevil research programs, the need for a more comprehensive research effort, and the areas which should be supported by USDA. As a result of the recommendations of this working group, Congress appropriated funds to establish the Boll Weevil Research Laboratory adjacent to the Mississippi State University campus and to augment the funding level at other USDA stations and the State Experiment Stations. The Boll Weevil Research Laboratory was dedicated in 1962 with the stated goal of ultimately eradicating the boll weevil.

During the period from 1945 through 1960, 250 research papers were published on the boll weevil with 77% on chemical control or resistance to insecticides (Table 1.)

The following chronological list summarizes research highlights of this period:

1944 - Ivy carried out early tests with DDT.

1949 - Ewing and Parencia reported on early-season control studies in Wharton County, Texas.

1950 - Isley used trap crop to concentrate weevils for insecticide use.

1955 - Roussel and Clower reported on resistance of boll weevil to organochlorine insecticides.

1958 - National Cotton Council passed a resolution that called for increased research and development to provide the technology for eradication. Vanderzant et al. laboratory-reared boll weevils for research tests.

1959 - Fye et al. researched hibernation habitat. Gaines reported on hibernation activity as related to temperature. Brazzel and Newsom described diapause. Brazzel reported on diapause control research. Earle et al. reported on larval diet.

1960 - Construction began on Boll Weevil Research Laboratory at Mississippi State. Knipling wrote about using insects for their own destruction. USDA hired new scientists to research boll weevils.

During the next decade, the research effort became somewhat more diverse as a result of the increased funding and drive toward eradication. Considerable progress was made in certain areas including, rearing, sterilization techniques, chemical application for reproductive diapause control, and pheromone attraction and trap development.

Events of this decade can be capsuled as follows:

1961 - Gast started improving laboratory-reared weevils. Research began at ARS Boll Weevil Research Laboratory. Lloyd and Merkl reported on the seasonal occurrence of weevil diapause in Mississippi. Lambremont reported on water content and respiration in diapause.

1962 - De Wilde reported on sensitivity of weevil stage to diapause stimuli. McLaughlin reported on infectivity of Beauveria. Davich and Lindquist used irradiation to sterilize boll weevils.

1963 - Haynes reported on chemosterilization of weevils. Gast and Vardell reported on mechanized rearing methods.

1964 - Cross and Mitchell observed weevil attraction in the field (Cross & Mitchell 1966). Keller et al. confirmed that an attractive substance was produced by male weevils. Whitcomb and Bell surveyed predatory arthropods in cotton.

1965 - Lincoln and Waddle reported on weevil resistance in frego bract cotton. Cross and Mitchell studied field mating behavior (Cross & Mitchell 1966). Davich et al. reported on low mating competitiveness of sterilized weevils. Nettles and Betz reported increase in glycogen content for diapausing weevils.

1966 - Gast and Landlin marked weevils by feeding larvae dye. McLaughlin et al. surveyed bacteria and fungi in field populations. Adkisson et al. compared two methods of diapause control.

1967 - Davis et al. reported on factors influencing emergence. Lloyd et al. reported on implications of photoperiod, temperature and food on diapausing condition. Hardee reported on pheromone. Cross et al. worked on trap design (Cross et al. 1969). Daum et al. reported on attractive bait work in Mississippi. Fryxell and Lukefahr suggested possible

primary host plant of boll weevil. Vanderzant published research on artificial diet. Cleveland and Scott reported on ULV malathion control experiments. Hardee et al. conducted attractancy test with olfactometer.

1968 - Burke segregated species of boll weevils in a taxonomic study. Fye reported on mechanisms of boll weevil spread. Cross and Hardee reported the concept of trapping overwintered weevils from hibernation sites. Tumlinson et al. reported on isolation of pheromone. Cross and Mitchell reviewed parasitism in Mexico. Davich et al. researched baits with pathogens, chemosterilants and dye. Bartlett described genetic marker in boll weevils.

1969 - Mitchell and Cross reported on details of field reproductive activity. Tumlinson et al. reported on chemical identification of pheromone. Taft et al. reported on nonattractiveness of red color.

1970 - Planning began for the pilot test experiment in south Mississippi. Davich et al. reported on long-range dispersal of weevils in Mexico. Leggett and Cross developed first trap to efficiently use grandlure (Leggett & Cross 1971). McKibben formulates pheromone in polyethylene glycol to bait traps (McKibben et al. 1971).

By 1969, in view of research developments and the urgency of a solution to the boll weevil problem, the National Cotton Council appointed a special study committee with a charge to: a) review current status of boll weevil suppression measures, and b) consider feasibility of actions with current technology to eliminate the boll weevil as a pest of cotton.

This committee concluded that adequate technology had been developed to expand large-scale field testing.

In 1970, the special study committee recommended that a Pilot Boll Weevil Eradication Experiment be conducted in south Mississippi and in adjacent areas of Alabama and Louisiana. The objective of the experiment was to assess the technical and operational feasibility of boll weevil eradication.

The pilot experiment was located in 30 counties in south Mississippi, five parishes in Louisiana, and two counties in Alabama. Within this area, there were approximately 24,000 acres of cotton in 1971 and 19,000 acres in 1972 and 1973, respectively. The area was divided into zones with an outer buffer zone of about 50 miles in width to reduce immigration to the inner core zone where evaluation was done.

Boll weevil reproduction was suppressed below detectable levels in 203 of 236 fields in the eradication zone. All of the infested fields were located in the northern one-third of the eradication zone and less than 25 miles from substantial populations farther north. In the southern two-thirds of the eradication zone, no reproduction could be detected in any of the 170 fields.

Following the completion of the trial eradication experiment and the evaluations, the status of the experiment was critiqued at a meeting in Memphis, Tennessee, on February 13-15, 1974. In view of the fact that USDA research had not "conclusively" demonstrated the feasibility of eradication, the cotton industry asked that USDA conduct another eradication experiment. The cotton industry also believed that utilizing other research findings developed since the previous trial, particularly the pheromone trap, was important.

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Eradication Experiment be conducted in South Mississippi and in

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A chronological synopsis of research events during this period is as follows:

1971 - Mitchell reported that temperature was a key factor in spring emergence. Hopkins et al. studied weevil movement into and out of cotton fields. Pfrimmer et al. reported effectiveness of insecticides for weevil control. Chestnut and Cross reported on parasitism survey. Jenkins and Parrott reported on the effectiveness of frego bract as a weevil resistance character in cotton. The Pilot Boll Weevil Eradication Experiment began on 24,000 acres in south Mississippi.

1972 - Mitchell et al. reported on the influence of rainfall on emergence. Hardee compared pheromone to caged live males. Roach et al. reported on traps in relation to overwintering sites. The chemical DDT is banned by EPA. Taft et al. reported on suppression of emerging early season boll weevils using integrated methods.

1973 - Cross reported on geographic distribution of boll weevils. Carter and Phillips described relation between diapause and changes in fruiting. Boyd et al. reported spring destruction of overwintered weevils in west Texas using wing traps. Mitchell et al. described relation between time of entrance into diapause and time of emergence. Jenkins et al. reported on frego bract field test. Final year of pilot eradication experiment in south Mississippi.

1974 - Cross reported on dispersal and migration. Mitchell and Hardee reported that traps capture weevils when conventional surveys fail and that trap capture is not representative of field population makeup. Hardee et al. published the best ratio for grandlure components. Niles et al. surveyed cotton cultivars that show resistance. Hardee et al. reported on a commercial gel formulation of grandlure. Villavaso and Earle found that males destined to enter diapause are less attractive to females.

1975 - Cross et al. published on the principal host plant of the boll weevil. Davis et al. reported on the survival of weevils in woods trash. Namken et al. reported on short season cottons. Jones developed a simulation model of boll weevil population dynamics.

1976 - McGovern et al. reported that overwintered males produce very small quantities of pheromone. Eden issued report from the Entomology Society of America Review Committee on the Pilot Boll Weevil Eradication Experiment. Mitchell and Hardee described the distance of grandlure attraction. Cross et al. reported on trap color. Mitchell et al. reported on infield trap used with insecticides for suppression.

It was decided to locate the Boll Weevil Eradication Trial in northeast North Carolina and southern Virginia. This was the eastern extremity of the Cotton Belt and cotton located outside the eradication zone was approximately 70 miles to the southwest. The area included 16,000 acres the first year and increased to 34,000 acres by the third and last year of the trial. About 20 percent of the cotton was located within the buffer

zone between the evaluation zone and outside non-program cotton. APHIS was the lead USDA agency for the eradication trial.

The components of the eradication trial consisted of:

1. Fall diapause treatments which began when diapause was detected and was continued until cotton was destroyed. Treatment intervals ranged from 7-d in September to 14-d intervals as the weather became colder at seasons end.
2. Pheromone traps to monitor populations and determine if in-season treatments were needed.
3. Dimilin applied to pinhead-square cotton as needed.
4. Sterile weevil releases in early fruiting period.
5. Defoliant applied to destroy food and breeding sites prior to stalk destruction.
6. Stalk destruction as soon as possible after harvest.
7. Monitoring for insects other than boll weevil (primarily *Heliothis* spp) and treating as needed.

The data for the eradication trial indicated eradication had been achieved by the second year of the three-year trial. They also found that the improved pheromone trap (with the pheromone in a controlled release formulation) would trap out very low populations of boll weevils in early spring.

The eradication trial was successfully completed in 1980, and a containment program was conducted during 1981-82 in the buffer zone to prevent reinfestation of the eradication area during the extensive evaluation process.

Research events during this period were as follows:

1977 - Boll Weevil Eradication Trial Program began in North Carolina. Rummel reported on the seasonal variation in height of weevil flight. Helms did his Ph.D. dissertation on the cotton boll weevil and the south. Hollingsworth correlated trap capture to number in overwintering sites. Haynes et al. reported on fractional irradiation of pupae as means of sterilization. Sikorowski et al. mass-reared weevils free of pathogens. Bottrell and Adkisson wrote on short-season techniques for weevil management in Texas. Optimum Pest Management trial began in Mississippi. Jordan studied fine structure and ultrastructure of weevil sensory receptors.

1978 - Borkovec et al. published work on chemosterilization. Moore et al. used diflubenzuron with acute irradiation to sterilize weevils. Sterling reported on the red imported fire ant as a predator of boll weevils. First full year of the Boll Weevil Eradication Trial program in North Carolina. Earle et al. reported on pheromone production in sterile weevils. Parencia wrote "One Hundred Twenty Years of Research on Cotton Insects in the United States."

1979 - Earle and Simmons reported on using diflubenzuron in acetone. Jones and Sterling reported on temperature thresholds for spring emergence and flight. Villavaso et al. researched sterile weevil competitiveness and pheromone production. Trial eradication program proving successful.

1980 - Ables et al. reported on diflubenzuron test in central Texas. Walker wrote about earliness in cotton to escape weevils. Rummel et al. developed a pheromone trap index system for predicting need for control. Villavaso et al. suggested new standard for sterilizing weevils. Wright et al. tested diflubenzuron plus 10 Krad irradiation to sterilize weevils. Lloyd et al. described detection and suppression of F_1 in fields.

1981 - Dickerson et al. reported on field evaluation of modified infield trap. Leggett et al. published on detection and prediction. Haynes et al. showed that diflubenzuron in acetone impaired weevil flight. Enfield et al. reported on genetic selection for post irradiation survival. Leggett et al. reported suppression of low level populations with infield traps. Reports of the biological evaluation of the eradication trial and OPM programs were published.

The program that was initiated on July 1, 1983, included all of the cotton acreage in North and South Carolina which was infested with boll weevils. This amounted to about 95,000 acres and included the buffer zone and southern portions of the original eradication trial area where immigration had occurred.

In 1984-1985, the same procedures were employed, and the program was successfully completed. They felt eradication had been achieved with the exception of a few scattered fields in the area and the buffer zone between South Carolina and Georgia outside the program area. The areas were addressed during the holding period until the next increment of the program could be initiated.

In 1985-1986, the program expanded to include western Arizona, southern California, and northwestern Mexico where heavy infestations had developed. Eradication has been completed in these areas, and the program was further expanded in 1987 into parts of Georgia, Alabama, all of Florida, and in 1988 to the remainder of the southwestern infestation in Arizona.

Significant research events during this period are summarized as follows:

1982 - Villavaso reported on field competitiveness of diflubenzuron fed, irradiated males. McKibben et al. reported on oviposition behavior. Mitchell et al. carried out field dispersal studies using Rubidium labeled weevils.

1983 - Scott et al. reported on the effects of diapause treatments on predaceous arthropods in cotton. Lloyd et al. showed suppression with traps. Frisbie et al. reported on short-season cottons. Bull et al. showed little effect on beneficials with diflubenzuron. Expanded eradication program began in North Carolina and South Carolina. "Cotton Insect Management with Special Reference to the Boll Weevil" was published by USDA.

1984 - McKibben and Cross reported on the use of traps to estimate the probability of a zero population of weevils. Villavaso and Thompson field evaluated competitiveness of weevils sterilized by feeding chemosterilants followed by irradiation or fumigation.

1985 - Western eradication program began in Arizona and California. McKibben et al. discovered potent feeding stimulant for the boll weevil. Ridgway et al. reported on the use of traps for treatment thresholds and population assessment. Wright wrote on effects on mobility of weevils by holding temperature and length of storage.

1986 - Villavaso et al. reported on effectiveness of sterile weevils against naturally occurring populations in commercially grown cotton. Dickens reported on orientation of the boll weevil to pheromone and volatile host compound in the laboratory. Wiygul reported the site of pheromone production in the male. Haynes looked at locomotor activity as effected by feeding. Burke et al. published a paper on the origin and dispersal of the boll weevil.

1987 - Eradication program expanded into Georgia, Florida, and Alabama. Dickens and Wiygul reported on conspecific effects on pheromone production. McGovern et al. reported on the boll weevil's ovipositional behavior of discrimination against damaged squares. Parvin et al. described the economics of cotton harvesting in the Mid South as related to shorter season production. Scott et al. noted the impact of early season use of selected insecticides on cotton arthropod populations and yield.

1988 - Dickens et al. reported on several factors that effects pheromone production. Prestwich et al. produced fluorinated analogues of the aldehyde components of the boll weevil

Becker [illegible]

[illegible] et al. discovered potent feeding [illegible]

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- Villavaso et al. reported on effects [illegible]

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1987 - [illegible]

Dickens and Wright reported on [illegible]

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pheromone. McKibben and Smith used simulation and an expert system to study boll weevil dispersal. North et al. tested fitness of radiation sterilized weevils produced through genetic engineering. Smith et al. reported on second-year of large release study with sterile weevils in Alabama. Progress in the Southeastern Boll Weevil Eradication Trial Program is slow because of heavy weevil pressure.

During the 1988 season there was a program area of 473,000 acres of cotton. These fields were treated on a field-by-field basis according to the trap catch. Average applications per acre ranged from 3.8 in the South Carolina buffer to 11.2 in the Eufaula, Alabama, area. For the program as a whole, an average of 8.6 applications were made through October 29, 1988.

Both 1988 and 1989 were difficult years for the program. Although progress was made, the program was behind schedule. Several factors contributed to this delay including: 1) underestimating boll weevil populations and reproductive potential in the expanded eradication area; 2) overestimating natural mortality, specifically, winter kill; 3) starting the initial diapause program with insufficient time to prepare; 4) involvement with environmental concerns, and a lawsuit that precluded normal operations and diluted staff time; and 5) inadequate funding for the program.

Low temperatures over the entire eradication area during December 1989 set the tone for an extraordinary successful suppression effort during 1990. Most boll weevil experts predicted that the unusually low winter temperatures would drastically reduce the spring emerging weevil population. Early trap captures throughout the program area bore this

out. The 1990 cotton crop got off to the best start in three years. Weevil catches were very low. In early June the percent of fields with zero weevils ranged from 60% for Albany, Georgia, to 94% for Jay, Florida. Spring spray operations began on May 13, 1990, and peaked during the period on or around June 15, at 118,065 acres. Although the 1990 program acres in the eradication zone were about 31% above 1989 levels, only 76% of the estimated projection area was sprayed. Progress of the program was summarized at the September 19, 1990, Southeastern Boll Weevil Eradication Meeting in Atlanta, Georgia, as "super good." Overall, weevils are low and all indications are that eradication is close at hand.

More recent research and eradication related events are summarized as:

1989 - Smith et al. conducted a large area sterile boll weevil release experiment in western Alabama. Haynes and Smith evaluated a new method of sterilizing boll weevils. Parrott et al. reported on feeding response of the weevil to ester extracts of host plants. McKibben and Smith reviewed weather factors affecting the long-range dispersal of the boll weevil. Wiygul and Smith discussed the use of a Geographic Information System in boll weevil research.

1990 - After a hard freeze in December 1989, eradication moved smoothly. McKibben et al. reported on the design of an attract-and-kill device for the boll weevil. Villavaso et al. reported on a lavender eye weevil that is a recessive sex-linked mutant of the boll weevil. Dickens published on the function of pheromone receptors in the boll weevil. McKibben et al. applied for patent on all-synthetic bait formulation for weevil control.

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1991 - McKibben et al. reported on field research results with the boll weevil bait stick. Villavaso et al. reported field tests with radiation resistant strains. McKibben et al. published a weevil dispersal model. Haynes et al. looked at diflubenzuron as a synergist for boll weevil insecticides. Mid-south states began planning for eradication expansion. Texas developed an eradication plan. Eradication in Arizona was completed. A large boll weevil bait stick test was conducted in Rutherford County, Tennessee. Wright & Chandler developed bait that employs a fungus as killing agent. Boll weevil parasite work revived in Texas.

1992 - Texas governor vetoed boll weevil bill. Expansion stalled in Alabama. Mississippi carried out a state-wide trapping program. Haynes and Smith researched the longevity of weevils on plants other than cotton. McKibben et al. applied for patent on insect control using insect attracticide compositions.

In 1991, more than 580,000 acres in 108 counties in Florida, Georgia, and southern Alabama were included in the expanded eradication program. Nearly all the counties in Florida, Georgia, and southern Alabama that are not in the buffer zone are 95 percent boll weevil free. Eradication treatments are continuing on the remaining 5% of fields. The Alabama counties bordering infested acres in central Alabama and Mississippi are considered part of the buffer zone. In addition, more than 60,000 acres from the previous buffer zone in South Carolina are included in the program.

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The Southwestern Boll Weevil Eradication Program began in 1985 and, like the Southeastern Boll Weevil Eradication Program, has been successful. The Southwestern Program differs from the Southeastern Program in several ways. It was found that boll weevils in the Southwest emerge from localized areas close to suitable overwintering sites, primarily near rivers, irrigation canals, and residential areas near cotton fields. In addition, compared to the Southeast, weevil populations were relatively low in the spring. Therefore, area-wide diapause treatments were not used the first fall of the southwest program as they had been in the southeastern states. In subsequent years selective diapause treatments were used to complete eradication (Planer 1989). The original Southwestern Program area covered 233,000 acres in southern California, western Arizona, and Northwest Mexico. In 1989, only 752 weevils were trapped in the entire area. In 1990, not a single boll weevil was trapped in the program area (Foster 1990).

The successes experienced in these widely varying environments located at opposite ends of the Cotton Belt suggests that eradication programs in the remainder of the Cotton Belt might be equally as successful.

Table 1. Breakdown by subject of research papers published from 1945 through 1960 on boll weevils

	1945- 1960
Chemical Control	193
Cultural Control	5
Biological Control	9
Host Plant Resistance	6
Biology and Life History	5
Ecological Studies	1
Effects of Weather	3
Hibernation	8
Diapause	4
Physiology and Morphology	4
Nutrition	7
Alternate-Host Plants	4
Attractants and Repellants	0
Total	249

Ables, J. R., S. L. Jones & M. J. Bee. 1977. Effect of diflubenzuron on beneficial arthropods associated with cotton. Southwestern Entomologist 2: 66-72

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Bottrell, D. G. & P. L. Addkison. 1977. Cotton insect pest management. Annual Review of Entomology 22: 451-481.

Boyd, F. J., J. R. Brazzel, W. F. Helms, R. J. Moritz & R. R. Edwards. 1973. Spring destruction of overwintered boll weevils in west Texas with wing traps. J. Econ. Entomol. 66: 507-510.

Burke, H. R. 1968. Geographic variation and taxonomy of *Anthonomus grandis* Boheman. Department of Entomology, Texas A&M University, ERD Contract Number 12.14-100-7733 (33), 152 p.

Burke, H. R., W. E. Clark, J. R. Cate & P. A. Fryxell. 1986. Origin and dispersal of the boll weevil. Bulletin of the Entomological Society of America 32(4): 228-238.

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